AIR POLLUTION IN THE SLOVAK REPUBLIC 2022

ANNEX

AIR QUALITY ASSESSMENT IN AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION

Air quality monitoring department
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

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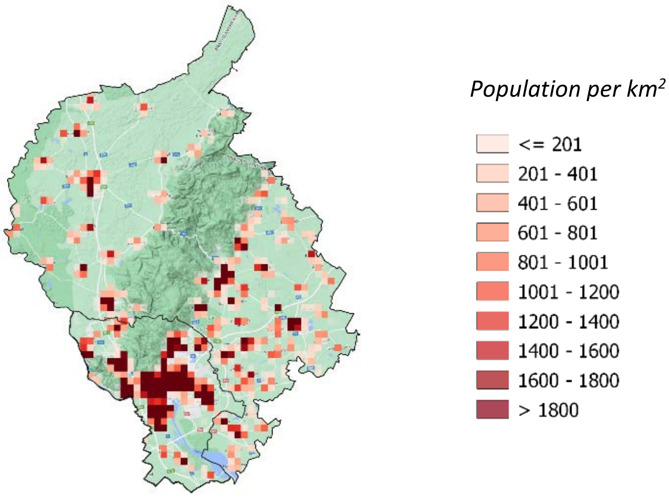
Version 1

1 DESCRIPTION OF TERRITORY OF AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION IN TERMS OF AIR QUALITY

For the purpose of air quality assessment, the territory of Slovakia is divided into zones and agglomerations (*https://www.shmu.sk/sk/?page=1&id=oko_info_az*). The territory of the Bratislava region includes agglomeration Bratislava (the territory of the capital city of the Slovak Republic Bratislava) and the zone of the Bratislava region (the Bratislava region without agglomeration Bratislava). **Fig. 1.1** shows population density in the Bratislava region.

Fig. 1.1 *Population density in the zone Bratislava region (Source: EUROSTAT, 2018).*



1.1 AGGLOMERATION BRATISLAVA (territory of the capital city of the Slovak Republic Bratislava)

Bratislava is located in a rugged terrain with altitudes ranging from 126 m (Čunovo) to 514 m (Devínska Kobyla). From southwest to northeast stretches the mountain of the Little Carpathians, the western part of Bratislava lies on the Záhorie lowland, the eastern and southeastern part is occupied by the Danubian lowland.

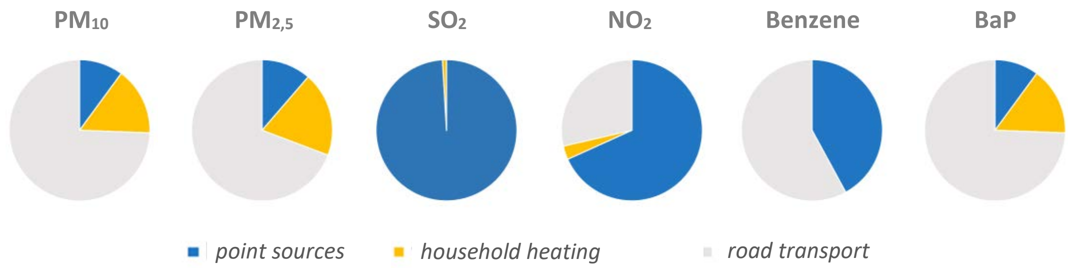
In the area of the Devín Gate, which separates the Hainburg Hills and the part of the Devín Carpathians, and in the area of the Lamač gate between the Devin Carpathians and the Pezinok Carpathians, there is an orographic increase in wind speed, which has a positive effect on the ventilation of the city. The Danube River flows through Bratislava and is used for shipping.

Air pollution sources in agglomeration Bratislava

The dominant source of air pollution in the capital city is road transport. The highest number of cars in Bratislava passes the D1 motorway bypass from the Harbour bridge in the direction to Žilina (on the most frequented section it is 93 344 vehicles on average daily, (12 762 trucks and 80 058 cars), the D2 motorway bypass from the Lafranconi in the direction of Austria and Hungary (82 646 vehicles, 11 913 trucks and 70 519 cars), the road No. 2 (59 121 vehicles, 3 273 trucks and 55 545 cars) running parallel to the R1 high speed road in Petržalka, road No 61 (Trnavská cesta – 48 720 vehicles, 3 420 trucks and 45 141 cars) and by road of 2nd class No 572 in the direction to Most pri Bratislave (35 051 vehicles, 2 915 trucks and 31 984 cars)[1].

[1] *https://www.ssc.sk/files/documents/dopravne-inzinierstvo/csd_2015/ba/scitanie_tabulka_ba_2015.pdf*

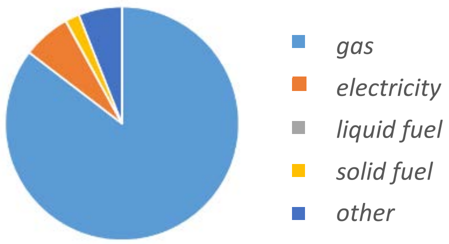
Fig. 1.2 *Share of different types of air pollution sources in total emissions in agglomeration Bratislava.*



Note: Medium and large air pollution sources registered in the NEIS database are identified for this purpose as "point sources".

Industrial sources of air pollution are less important here in terms of their contribution to local air pollution from basic pollutants. Emissions of sulphur oxides are formed almost exclusively by an industrial source - the refinery, but their values have decreased significantly over the last decades and the limit values for SO_2 concentrations in the air are not currently exceeded, as for other basic pollutants except NO_2, which, according to air quality measurements, exceeded the limit value at the AMS Trnavské mýto in 2018. The share of different types of sources in emissions in the agglomeration Bratislava is shown in **Fig. 1.2**.

Fig. 1.3 *Share of different types of fuel used for heating in family houses* [2].



According to the Population and Housing Census (PHC) 2021 data, natural gas is mainly used for heating of family houses in the zone, the share of solid fuels is the lowest compared to the other zones (this is probably mainly about fireside heating in the transitional seasons).

1.2 ZONE BRATISLAVA REGION (without agglomeration Bratislava)

The zone Bratislava region covers the area of the region without agglomeration Bratislava. The Bratislava region is the smallest region in Slovakia in terms of area. It includes the southern part of the Little Carpathians, the Záhorie region and the greater part of the Danube Lowland. The surface is mostly flat. The altitude of the territory ranges from 126 m a.s.l. to 754 m a.s.l. (mount Vysoká). The most populous towns are the district towns of Pezinok, Senec and Malacky. The average population density in the Malacky district is significantly lower than in other districts.

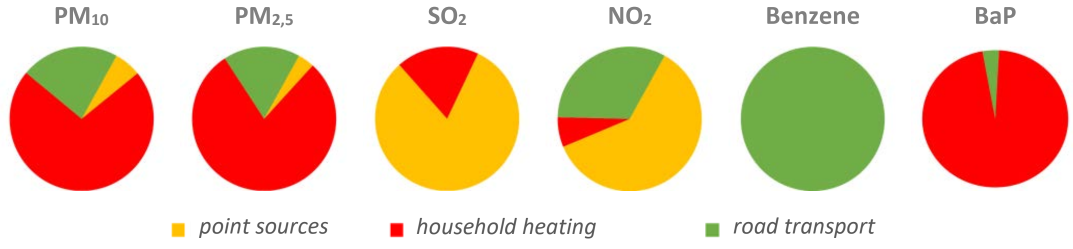
Air pollution sources in zone Bratislava region

The significant source of air pollution in the Bratislava region is road transport, which concentrates mostly on motorway routes. The results of the national traffic census in 2015 show that the D1 motorway leading to Senec reaches a daily intensity of 62 652 vehicles on average (10 385 trucks and 52 260 cars), while the D2 motorway leading from Bratislava to Malacky and Brno in the section near Stupava 32 968 vehicles (9 787 trucks and 23 132 cars) [3].

[2] *https://www.scitanie.sk*

[3] *https://www.ssc.sk/sk/cinnosti/rozvoj-cestnej-siete/dopravne-inzinierstvo/celostatne-scitanie-dopravy-v-roku-2015/bratislavsky-kraj.ssc*

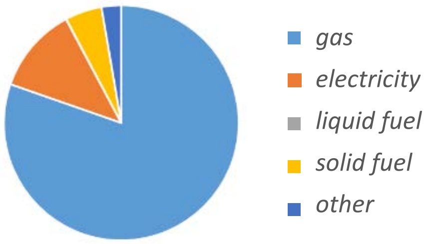
Fig. 1.4 *Share of different types of air pollution sources in total emissions in the zone Bratislava region.*



Note: Medium and large air pollution sources registered in the NEIS database are identified for this purpose as "point sources".

Industrial sources of air pollution, with the exception of cement factories (whose contribution may be reflected mainly in the coarse size fraction of dust particles), are less significant in terms of their contribution to local air pollution by basic pollutants.

Fig. 1.5 *Share of different types of fuel used for heating in family houses [4].*



According to the Population and Housing Census (PHC) 2021 data, natural gas is mainly used for heating in family houses in the zone, although to a lesser extent in comparison with agglomeration Bratislava. Solid fuels are more likely to be used in rural settlements with good availability of firewood.

2 AIR QUALITY MONITORING STATIONS IN AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION

Tab. 2.1 and **Tab. 2.3** contains information on air quality monitoring stations in agglomeration Bratislava and in the zone Bratislava region:

- international EoI code, station characteristics according to dominant sources of air pollution (traffic, background, industrial), type of monitored area (urban, suburban, rural/regional) and geographical coordinates;
- monitoring programme. Continuous monitoring instruments provide hourly average concentrations of PM_{10}, $PM_{2.5}$, nitrogen oxides, sulphur dioxide, ozone, carbon monoxide and benzene. The SHMÚ test laboratory analyses heavy metals and polycyclic aromatic hydrocarbons as part of manual monitoring, resulting in 24-hour average values.

[4] *https://www.scitanie.sk*

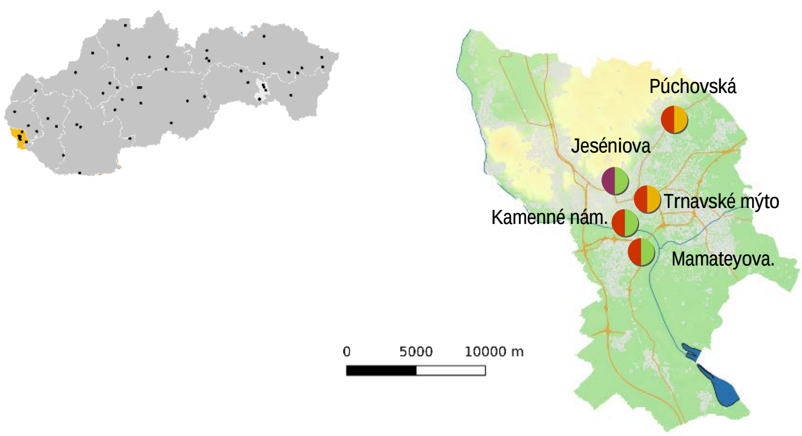
2.1 AGGLOMERATION BRATISLAVA (territory of the capital of the Slovak Republic Bratislava)

In agglomeration Bratislava, air quality is monitored at 5 stations. In addition to the traffic station at Trnavské mýto, which is one of the locations with the highest traffic intensity and the highest concentration of pedestrians in the city, in 2021 a new monitoring station in Rača, Púchovská started to operate.

Housing estate is represented by the urban background station in Petržalka on Mamateyova street, additional monitoring stations are located in the residential area in Koliba, Jeséniova (monitors background levels of pollution in the suburban area) and in the centre of the town on Kamenné square (monitors urban background).

Tab. 2.1 *Air quality monitoring programme in agglomeration Bratislava.*

Agglomeration Bratislava									Measurement programme									
									Continuously								Manually	
District	Code EoI	Name of station	Type of area	Type of station	Geographical longitude	Geographical latitude	Altitude [m]	PM_{10}	$PM_{2,5}$	NO, NO_2	SO_2	O_3	CO	Benzene	Hg	As, Cd, Ni, Pb	BaP
Bratislava I	SK0004A	Bratislava, Kamenné nám.	U	B	17°06'49"	48°08'41"	139										
Bratislava III	SK0002A	Bratislava, Trnavské mýto	U	T	17°07'44"	48°09'30"	136										
Bratislava III	SK0048A	Bratislava, Jeséniova	S	B	17°06'22"	48°10'05"	287										
Bratislava V	SK0001A	Bratislava, Mamateyova	U	B	17°07'31"	48°07'29"	138										
Bratislava III	SK0061A	Bratislava, Púchovská	U	T	17°09'29"	48°12'41"	145										
							Total	5	5	4	3	2	2	2	0	1	3



Type of area
U – urban
S – suburban
R – regional

Type of station
B – background
T – traffic
I – industrial

In addition to air quality monitoring, precipitation quality is also analysed at the suburban background monitoring station Bratislava, Jeséniova. The monitoring programme is given in **Tab. 2.2**, the sampling period and sampling interval was one month.

Tab. 2.2 *Precipitation measurement programme at monitoring station Bratislava, Jeséniova.*

	pH	Conductivity	Sulphates (SO_4^{2-})	Nitrates (NO_3^-)	Chlorides (Cl^-)	Ammonium ions ($NH4^+$)	Alkaline ions (K^+, Na^+, Ca^{2+}, Mg^{2+})	Lead (Pb)	Arsenic (As)	Cadmium (Cd)	Nickel (Ni)	Chromium (Cr)	Copper (Cu)	Zinc (Zn)
Bratislava, Jeséniova	x	x	x	x	x	x	x	x	x	x	x	x	x	x

2.2 ZONE BRATISLAVA REGION (without agglomeration Bratislava)

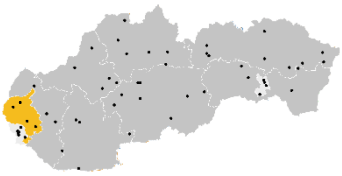
In the Bratislava region, air quality is monitored at 4 stations. Station monitoring the impact of traffic is located in the centre of Malacky and a new monitoring station has been added in Senec since 2021. Both stations in the above-mentioned district towns are located at intersections with heavy traffic and large numbers of pedestrians.

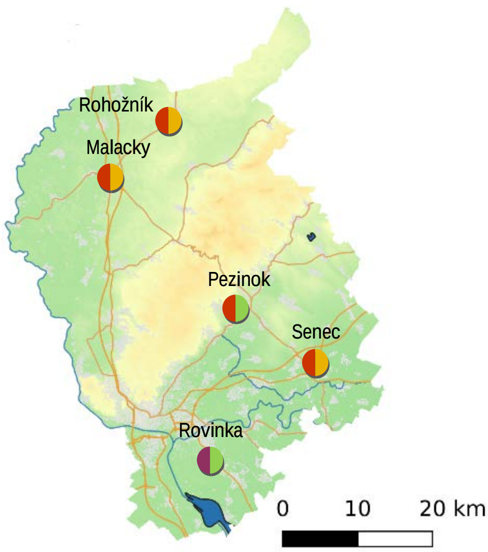
Air pollution in residential zones outside the main traffic routes is monitored by stations in the district town of Pezinok and the village of Rovinka. Air quality monitoring Rovinka is also carried out due to the proximity of the Slovnaft refinery. The NMSKO station in Pezinok is one of the new stations added as part of the latest extension of the NMSKO network.

Tab. 2.3 Air quality monitoring programme in the zone Bratislava region.

Zone Bratislava region (without agglomeration Bratislava)								Measurement programme									
								Continuously								Manually	
District	Code EoI	Name of station	Type of area	Type of station	Geographical longitude	Geographical latitude	Altitude [m]	PM_{10}	$PM_{2.5}$	NO, NO_2	SO_2	O_3	CO	Benzene	Hg	As, Cd, Ni, Pb	BaP
Malacky*	SK0407A	Malacky, Mierové nám.	U	T	17°01'09''	48°26'13''	162										
Pezinok	SK0075A	Pezinok, Obrancov mieru.	U	B	17°15'35''	48°17'00''	150										
Rohožník*	SK0077A	Rohožník, Senická cesta	U	T	17°10'17''	48°27'25''	201										
Rovinka	SK0076A	Rovinka, mobile station	S	B	17°13'50''	48°05'59''	129										
Senec	SK0068A	Senec, Boldocká	U	T	17°24'16''	48°13'23''	126										
							*Total	4	3	4	2	2	3	2	0	0	1

* The Malacky station was in operation until 29 April 2022, in June it was replaced by the Rohožník station. The stations did not monitor air pollution in parallel, therefore the sum of stations is not correct.





Type of area
U – urban
S – suburban
R – regional

Type of station
B – background
T – traffic
I – industrial

3 ASSESSMENT OF AIR QUALITY IN AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION

This chapter contains an assessment of air quality in agglomeration Bratislava and the zone Bratislava region based on monitoring.

Tab. 3.1 *Assessment of air pollution according to limit values for protection of human health and numbers of alert threshold exceedances in the zone Bratislava region – 2022.*

AGGLOMERATION Zone		Protection of human health									IT 2)	AT 2)
	Pollutant	SO_2		NO_2		PM_{10}		$PM_{2,5}$	CO	Benzene	PM_{10}	PM_{10}
	Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h 1)	1 year	12 h	12 h
	Parameter	number of exceedances	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average	number of exceedances [h]	number of exceedances [h]
	Limit value [µg·m⁻³]	350	125	200	40	50	40	20	10 000	5	100	150
	Maximum number of exceedances	24	3	18		35						
BRATISLAVA	Bratislava, Kamenné nám.					3	19	12			0	0
	Bratislava, Trnavské mýto			0	31	9	24	15	780	0.54	0	0
	Bratislava, Jeséniova	0	0	0	9	0	15	11			0	0
	Bratislava, Mamateyova	0	0	0	16	1	18	11			8	0
	Bratislava, Púchovská	0	0	0	13	1	19	13	694	0.35	0	0
Bratislava region	Malacky, Mierové nám. 3)	0	0	0	21	0	22	14	1 334	0.71	0	0
	Pezinok, Obrancov mieru			0	9	3	16	13			0	0
	Rohožník, Senická 3)	0	0	0	11	1	21	14	1 426	0.76	0	0
	Rovinka	1	0	0	12	0	19		667	0.86	0	0
	Senec, Boldocká			0	20	8	20	14	836		9	0

≥ 90% of valid measurements

1) *eight-hour maximum concentration*

2) *IT, AT - duration of exceedance (in hours) of the information threshold (IT) and alert threshold (AT) for PM_{10}*

3) *The Malacky monitoring station ceased measurement on 29 April 2022 and was replaced by the AMS in Rohožník in June 2022, there are not enough valid measurements to assess the exceedance of limit values on a yearly basis.*

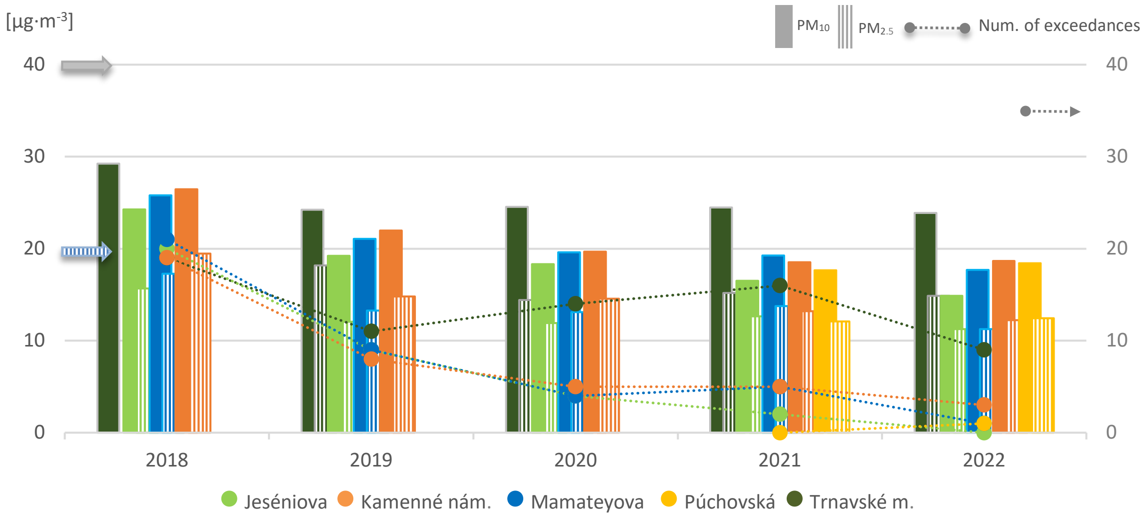
With the exception of the monitoring stations Rohožník, Senická and Malacky, Mierové nám. in accordance with the Regulation of the Ministry of Environment of the Slovak Republic No. 244/2016 Coll. of Acts on air quality, as amended, the required proportion of valid values was met at the other monitoring stations in the Bratislava agglomeration and in the Bratislava region zone.

3.1 AGGLOMERATION BRATISLAVA

3.1.1 PM_{10} and $PM_{2.5}$

Fig. 3.1 shows the average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of days with an average daily concentration of PM_{10} above 50 µg·m^{-3} according to the results of measurements at monitoring stations in Bratislava agglomeration in the years 2018 – 2022.

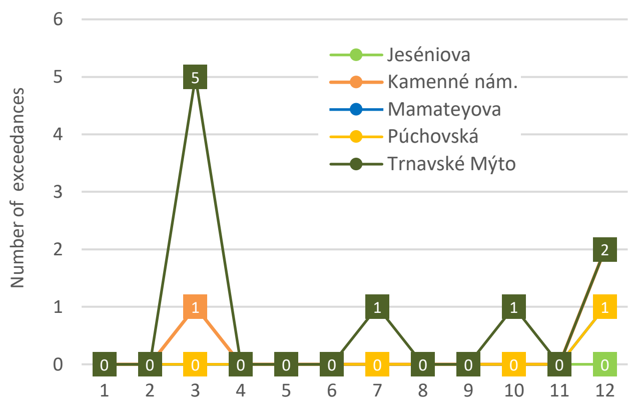
Fig. 3.1 *Average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of exceedances of the daily limit value for PM_{10}.*



Number of exceedances - daily average concentrations higher than 50 µg·m^{-3}.

*Arrows show the limit values, **blue striped** $PM_{2,5}$ (average annual concentration: 20 µg·m^{-3}); **grey solid** PM_{10} (average annual concentration: 40 µg·m^{-3}); **grey dotted right** number of exceedances (average daily PM_{10} concentration of 50 µg·m^{-3} must not be exceeded more than 35 times in a calendar year).*

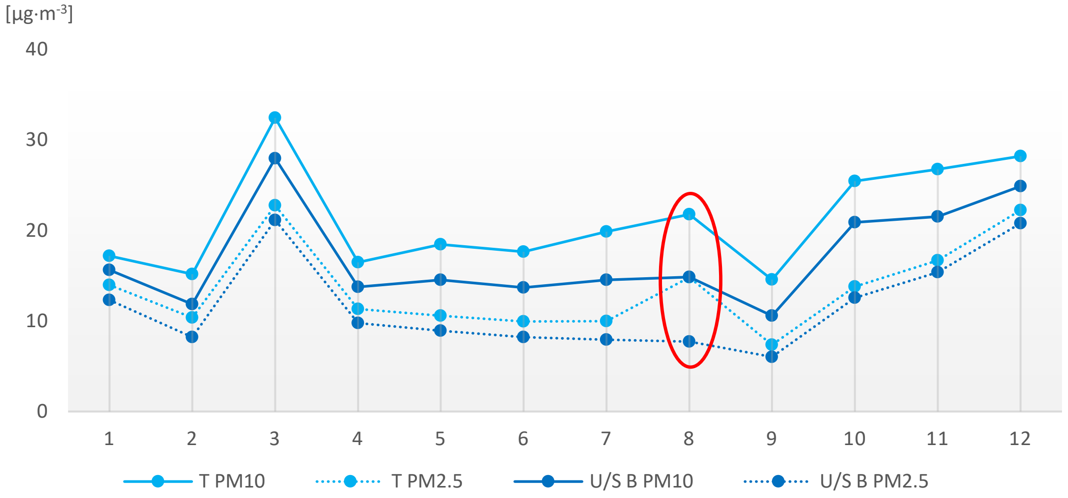
Fig. 3.2 *Number of PM_{10} daily limit value exceedances per month in 2022.*



The limit value for the annual average PM_{10} concentration (40 µg·m^{-3}) in the Bratislava agglomeration was not exceeded at any of the monitoring stations. As expected, the highest annual average PM_{10} concentration of 24 µg·m^{-3} in Bratislava was recorded at the Trnavské Mýto traffic station, which is the same value as in 2021. It should be noted that demolition works of the Istropolis building were carried out in the vicinity of the station throughout the year, which clearly contributed to the increase in PM_{10} concentrations. The level of PM_{10} pollution in the urban background locations in 2022 was at a similar level (18 – 19 µg·m^{-3}). Lower concentrations were recorded at the suburban background station Jeséniova, located in the foothills of the Little Carpathians at Koliba. The limit value for the number of exceedances (35) of the average daily concentration of PM_{10} (50 µg·m^{-3}) was not exceeded at any station (**Fig. 3.1**) and the WHO limit (maximum 3 – 4 exceedances) would also be met at all background stations. The number of daily exceedances was also significantly lower at AMS Trnavské mýto: 9 exceedances in 2022 compared to 16 in 2021. **Fig. 3.2** shows the number of exceedances of the limit value for the average daily concentration of PM_{10} for each month of the year in the Bratislava agglomeration, the highest number of exceedances was recorded in March. At the station Bratislava, Jeséniova no exceedances of the daily limit value were recorded for the whole year.

A total of 14 exceedances were recorded at all stations in Bratislava in 2022, which is half the number recorded in 2021. One exceedance was recorded at Trnavské mýto in July, which is unusual for this month. This was probably due to demolition works near the station associated with the occurrence of an anticyclone, which caused unfavourable dispersion conditions for the dispersion of dust from the construction site.

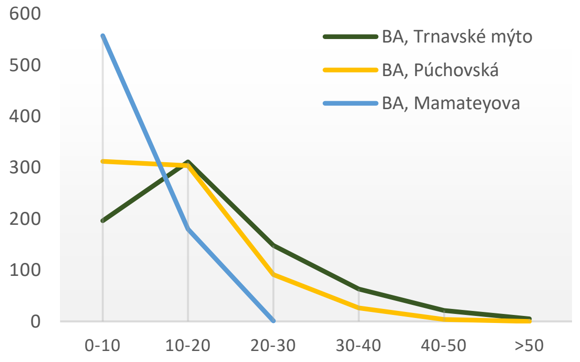
Fig. 3.3 *Average monthly concentrations of PM_{10} and $PM_{2.5}$ in agglomeration Bratislava by station type.*



***T PM10** and **T PM2.5** – average monthly concentration of PM_{10} a $PM_{2.5}$ at the urban traffic station Trnavské mýto and Púchovska; **U/S B PM10** and **U/S B PM2.5** – average monthly concentration of PM_{10} and $PM_{2.5}$ at the urban/suburban background station Jeséniova, Kamenné námestie, Mamateyova.*

Compared to other zones, monthly concentrations (**Fig. 3.3**) show the smallest differences in PM_{10} concentrations between colder and warmer months. This is because central heating of households prevails in Bratislava having much lower emissions of particulate matter. Compared to 2021, when we recorded maximum monthly PM_{10} concentrations in February, the maximum in 2022 was in March, which was characterized by unfavourable dispersion conditions during several anticyclonic situations, during the heating season. Concentrations of PM_{10} in the typically wintry months of January and February, which in contrast were above-normal in temperature, were low – on par with the summer period. The largest difference between traffic and background stations was observed in August. This can be attributed to demolition works near Trnavské mýto station. If we compare the hourly average PM_{10} concentrations in August at Trnavské Mýto with other Bratislava stations (**Fig. 3.4**), we can see large differences in their distribution – at Mamateyova station the majority of concentrations were in the range of 0 – 10 µg·m^{-3} and concentrations higher than 30 µg·m^{-3} did not occur at all, at Púchovská station the lowest concentrations were also much more strongly represented than at Trnavské mýto, where, on the contrary, concentrations above 30 µg·m^{-3} occurred at a much higher rate. In other months of the year, such marked differences in the distribution of PM_{10} concentrations did not occur.

Fig. 3.4 *Distribution of hourly PM_{10} concentrations in August 2022 at Trnavské mýto, Púchovská str. and Mamateyova str.*

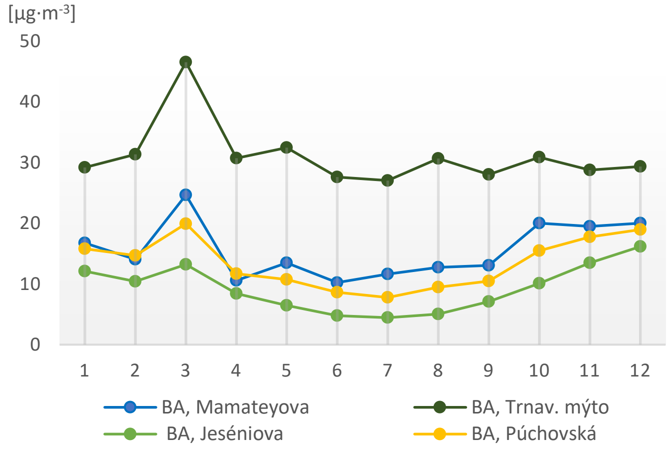


In **Fig. 3.3**, $PM_{2.5}$ concentrations are shown by the dashed line. Like PM_{10}, $PM_{2.5}$ does not show as pronounced a seasonal pattern in Bratislava as other monitoring stations in Slovakia. Although Bratislava is the region with the best air quality in Slovakia, the average annual concentration of $PM_{2.5}$ at all monitoring stations slightly exceeds the value of 10 $\mu g \cdot m^{-3}$ and therefore the capital city does not meet the revised WHO health recommendations for the fine fraction of PM effective from September 2021 (5 $\mu g \cdot m^{-3}$). Bratislava in the ranking of European cities *How clean is the air in my city?* (EEA, 2023) based on fine $PM_{2.5}$ values measured in the air over the 2021 – 2022 period, ranked 244th out of 375 cities assessed.

3.1.2 Nitrogen dioxide

Nitrogen dioxide monitoring is carried out at four stations in agglomeration Bratislava, the average monthly values for each station are shown in **Fig. 3.5**.

Fig. 3.5 *Average monthly NO_2 concentrations.*

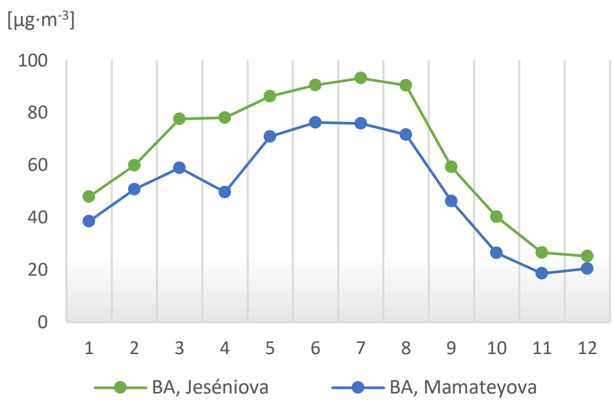


The main source of NO_2 emissions is road transport. At the Trnavské mýto traffic station, the second highest annual average NO_2 concentration in Slovakia was measured in 2022 (31 $\mu g \cdot m^{-3}$), which is a consequence of the high traffic intensity in this location. However, the limit value (40 $\mu g \cdot m^{-3}$) was not exceeded. In other locations in Bratislava, the level of NO_2 pollution is at a much lower level, as illustrated in **Fig. 3.5**. The monthly NO_2 concentrations at the Púchovská traffic station are at a lower level than at the Mamateyova station, which is classified as background station. The station on Jeséniova street (the average annual NO_2 concentration here reached 9 $\mu g \cdot m^{-3}$) is the only one in Bratislava that met – albeit narrowly – the WHO recommendations (10 $\mu g \cdot m^{-3}$). These are significantly stricter than the EU limit values.

3.1.3 Ozone

Ozone monitoring is carried out in the capital at two monitoring stations, Mamateyova and Jeséniova. The latter is located at a higher altitude in Koliba, at the foothills of the Little Carphatians. Higher concentrations are measured at this station than at Mamateyova street in Petržalka.

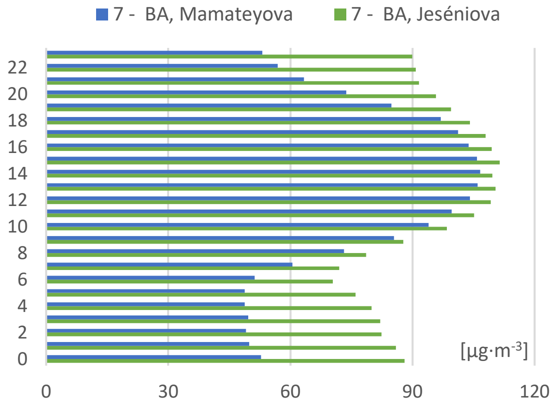
Fig. 3.6 *Average monthly O_3 concentrations in 2022.*



The highest concentrations of ground-level ozone generally occur in warm months with high sunshine intensity (**Fig. 3.6**). **Fig. 3.7** and **Fig. 3.8** show the so-called daily course of O_3 concentration. It shows that concentrations increase with sunrise, peaking around midday and gradually decreasing in the evening to a minimum, which occurs early in the morning. Large differences in ground-level ozone concentrations are also observed in the warm and cold seasons.

Fig. 3.7 *Daily O_3 concentration in January 2022.*

Fig. 3.8 *Daily O_3 concentration in July 2022.*



The number of days with exceedances of the ground-level ozone target value shows **Tab. 3.2**.

Tab. 3.2 *Number of days with exceedances of the ground-level ozone target value for the protection of human health.*

Station	2020	2021	2022	Average 2020 – 2022
Bratislava, Jeséniova	17	23	37	26
Bratislava, Mamateyova	12	15	25	17

≥ 90% requested valid data *Exceedance of the target value is marked in red.*

Note: The target value for the protection of human health for ground-level ozone is set by Regulation of MoE SR No. 244/2016 Coll. of Acts on air quality, as amended: "The highest daily 8-hour mean concentration shall not exceed 120 µg·m^{-3} for more than 25 days per calendar year on average for three years".

Ground-level O_3 is formed in the atmosphere in the presence of solar (UV-B) radiation by the chemical reaction of nitrogen oxides (NO, NO_2) and volatile organic compounds or carbon monoxide. The source of nitrogen oxides are combustion processes, in urban agglomeration conditions mainly road transport, in the case of Bratislava also refinery. Road transport is also a source of emissions of volatile organic compounds, but also industrial sources and, in the warm half of the year, vegetation is an important source. However, ground-level O_3 is also decomposed by reaction with NO at certain concentrations (so-called ozone titration), therefore O_3 concentrations are lower in areas with higher NO.

The target value for the protection of human health for ozone was exceeded in the assessment years 2020 – 2022 in the Bratislava agglomeration at the monitoring station Bratislava, Jeséniova. The reason for the lower values of ground-level ozone in Mamateyova street compared to Jeséniova street is probably the aforementioned titration of ozone by nitric oxide, which occurs in higher concentrations in the vicinity of Mamateyova street than in Jeséniova street due to the influence of road traffic and the refinery, which is a source of emissions of volatile organic compounds.

3.1.4 Benzo(a)pyrene

The pollutant benzo(a)pyrene is monitored at three monitoring stations in the Bratislava agglomeration – at Jeséniova street, Trnavské mýto and Púchovská street. None of the stations exceeded the target value for the annual average concentration (1 ng·m^{-3}). Concentrations in the period from May to September were low at all stations with monthly average values up to 0.1 ng·m^{-3}. As with PM_{10}, the highest concentrations were recorded in March (**Fig. 3.9**). In the assessment year 2022, a maximum concentration of 3.2 ng·m^{-3} was measured in December at Trnavské mýto. The histogram in the figure (**Fig. 3.10**) shows that high concentrations of benzo(a)pyrene are relatively rare in Bratislava, with 332 of the 429 measurements below 0.5 ng·m^{-3} and 10 measurements above 2 ng·m^{-3}.

Fig. 3.9 *Average monthly concentrations of B(a)P in 2022.*

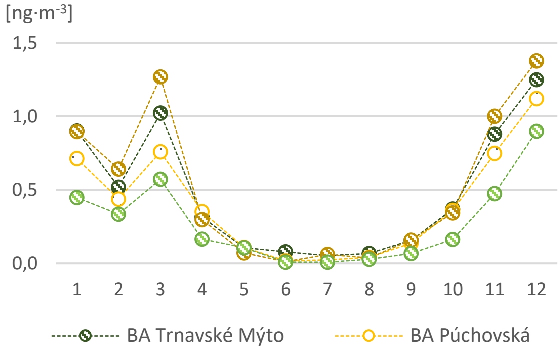
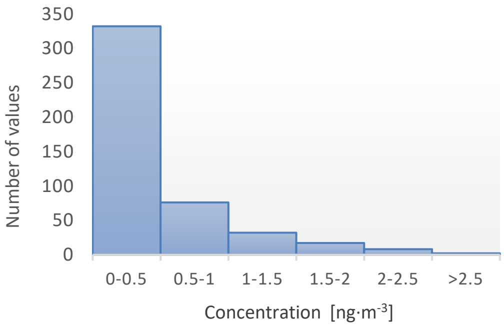


Fig. 3.10 *Histogram of daily B(a)P concentrations in 2022.*



Tab. 3.3 *Assessment of benzo(a)pyrene air pollution.*

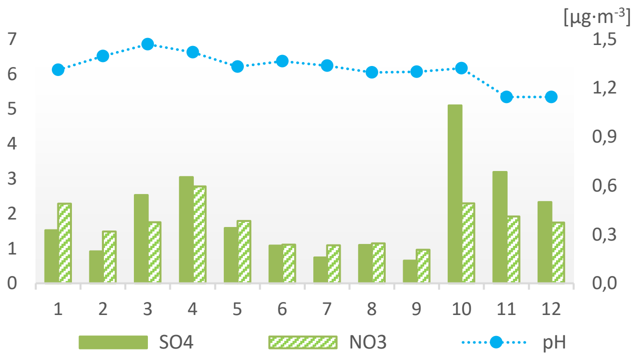
	2018	2019	2020	2021	2022
Target value [ng·m^{-3}]	1.0	1.0	1.0	1.0	1.0
Bratislava, Jeséniova		0.2	0.2	0.3	0.3
Bratislava, Trnavské mýto	0.9	0.4	0.5	0.5	0.5
Bratislava, Púchovská				0.9	0.4

≥ 90% requested valid data

3.1.5 Chemical composition of precipitation

The quality of precipitation in Bratislava is monitored at the Jeséniova station in Koliba. In 2022, the amount of precipitation was very unevenly distributed in the individual months, with below-average precipitation at the beginning of the year and above-average precipitation in May, June and September. Wet deposition NO_3^- was 0.15 g/m^2/year, SO_4^{2-} likewise 0.15 g/m^2/year. Wet deposition of lead was at the level of 1 mg/m^2/year. The annual average pH value was 6.1 (**Fig. 3.11**). Unusually high pH values were observed in February – April, mainly due to high calcium and potassium (in March); these ions are associated with anthropogenic emissions from acid and combustion processes. Detailed monitoring results are presented in Chapter 3.4 Regional Monitoring of *Air pollution in the Slovak Republic 2022 Report*.

Fig. 3.11 *Monthly concentration values SO_4^{2-} NO_3^- and pH in 2022.*

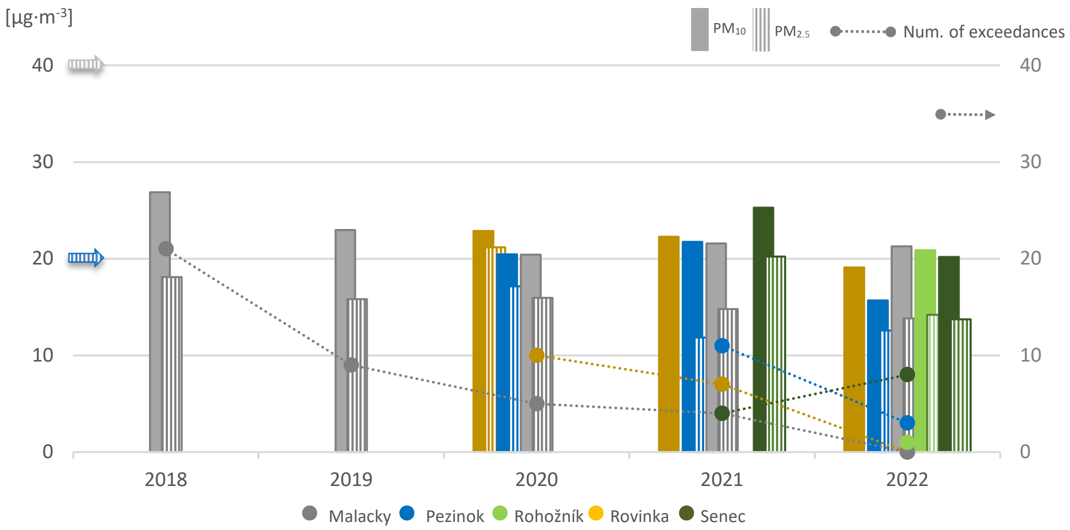


3.2 ZONE BRATISLAVA REGION

3.2.1 PM_{10} a $PM_{2.5}$

Fig. 3.12 shows the average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of days with average daily concentrations above 50 µg·m^{-3} according to the results of measurements at monitoring stations in the zone Bratislava region in years 2018 – 2022.

Fig. 3.12 Average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of exceedances of the daily limit value for PM_{10}.



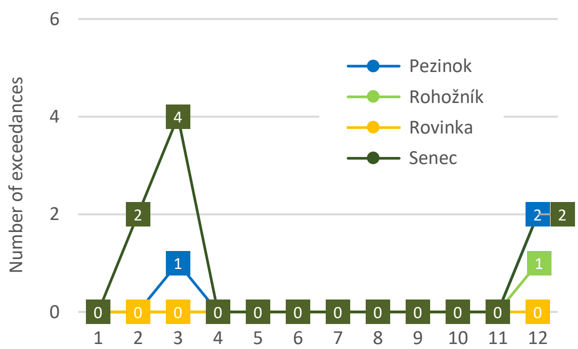
Number of exceedances - daily average concentrations higher than 50 µg·m^{-3}.

*Arrows show the limit values, **blue striped** $PM_{2,5}$ (average annual concentration: 20 µg·m^{-3}); **grey striped** PM_{10} (average annual concentration: 40 µg·m^{-3}); **grey dotted right** number of exceedances (average daily PM_{10} concentration of 50 µg·m^{-3} must not be exceeded more than 35 times in a calendar year).*

The Senec, Boldocká station started measuring PM_{10} in September 2021. The NMSKO station in Malacky ceased operation in April 2022 and was replaced by the NMSKO station in Rohožník (started operation in June 2022). Therefore, the average value and number of air pollution exceedances in Malacky and Rohožník do not reflect the situation for the whole year 2022.

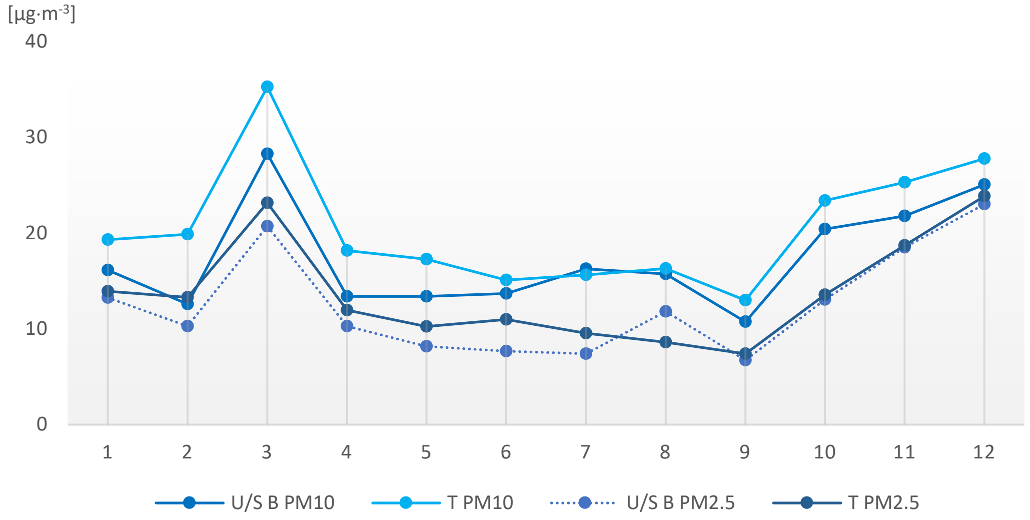
In the zone Bratislava region in the NMSKO monitoring network, new monitoring stations have been added since 2020. The last change took place in 2022 – it was the transfer of the traffic station from Malacky to Rohožník. For this reason, we do not yet have enough data to compare pollution levels at the stations over the last 5 years. However, we can state that in 2022 the limit value for the annual average concentration of PM_{10} (40 µg·m^{-3}) was not exceeded. Also, the limit value for the number of exceedances (maximum 35) of the average daily concentration of PM_{10} (50 µg·m^{-3}) was not exceeded by any station. In contrast, the number of exceedances was significantly lower compared to 2021 (**Fig. 3.12**), noting that the traffic station in Senec was only measured from September onwards in 2021, so the number of exceedances in 2021 covered only 4 months. Compared to the previous year, the average annual concentration was also lower at the stations that had a sufficient number of measurements in both years 2021 – 2022: in Pezinok 16 µg·m^{-3} and in Rovinka 19 µg·m^{-3}.

Fig. 3.13 Number of PM_{10} daily limit value exceedances PM_{10} per month in 2022.



No exceedances of the daily PM_{10} limit (50 µg·m^{-3}) were recorded in Rovinka in 2022, and three exceedances were recorded in Pezinok – one in March, when a significant cooling occurred after an above-average warm start of the year, and the other two exceedances occurred in early December. Similarly, at the traffic station in Senec, the highest number of exceedances of the daily PM_{10} limit was recorded in March (**Fig. 3.13**). As there were several anticyclones and also days with very low temperatures in March, it can be assumed that supplementary heating with solid fuel (wood) in houses at this station contributed to the increase in particulate matter emissions.

Fig. 3.14 *Average monthly concentrations of PM_{10} and $PM_{2.5}$ in the zone by type of station.*



***T PM10** and **T PM2.5** – average monthly concentration of PM_{10} and $PM_{2.5}$ at the urban traffic stations: Rohožník and Senec (station Rohožník started measuring in June 2022); **U/S B PM10** and **U/S B PM2.5** – average monthly concentration of PM_{10} and $PM_{2.5}$ at the urban/suburb background stations: Pezinok and Rovinka;*

The course of average monthly concentrations of PM_{10} and $PM_{2.5}$ in 2022 does not have a significant seasonal trend (**Fig. 3.14**), with a more pronounced increase in concentrations observed in March. The first two months of the winter of the year were warmer than average, which resulted in PM_{10} and $PM_{2.5}$ concentrations at the level of the summer months.

Increased concentrations of $PM_{2.5}$ fine particles in the air are a risk ones, mainly because of their unfavourable effects on human health. In the zone Bratislava region, PM_{10} and $PM_{2.5}$ do not show such a pronounced seasonal pattern as in other areas in Slovakia. Also in this zone, the mean annual concentration at all monitoring stations was higher than the WHO recommendation (up to 5 µg·m^{-3}). This recommendation was not met in any month of the year, including summer, when $PM_{2.5}$ concentrations tend to be lowest.

3.2.2 Nitrogen dioxide

Nitrogen dioxide monitoring is carried out at four stations in the zone, the average monthly values for each station are shown in **Fig. 3.15**.

The main source of NO_2 emissions is road transport. The highest concentrations for this reason are recorded at the traffic station – in this zone in Senec (20 µg·m^{-3}). The maximum measured hourly concentration at this station reached 140 µg·m^{-3}. The histogram of values at AMS in Senec illustrates **Fig. 3.16** – hourly NO_2 concentrations in the range of 0 – 30 µg·m^{-3} are the most common, with high concentrations above 50 µg·m^{-3} recorded sporadically. The traffic station in Malacky measured only the first four months – the values of monthly concentrations in these months were approximately at the level of the monitoring station in Senec, in the previous year the measured concentrations in Malacky were lower, at the level of the urban background station in Pezinok. The monitoring station in Rohožník started measuring in June and the measured concentrations here reached the level of urban/suburban background stations, as illustrated in **Fig. 3.15**. Maximum concentrations were recorded in March, as for other pollutants, reflecting the cooling and worsened dispersion conditions. NO_2 concentrations are at relatively low levels in the zone Bratislava region, the WHO recommendation (10 $\mu g \cdot m^{-3}$) for the annual average NO_2 pollution level was met by the station in Pezinok (9 $\mu g \cdot m^{-3}$). The WHO recommendations are more reflective of the impact of pollution on health and are considerably stricter than the EU limits.

Fig. 3.15 *Average monthly NO_2 concentrations.*

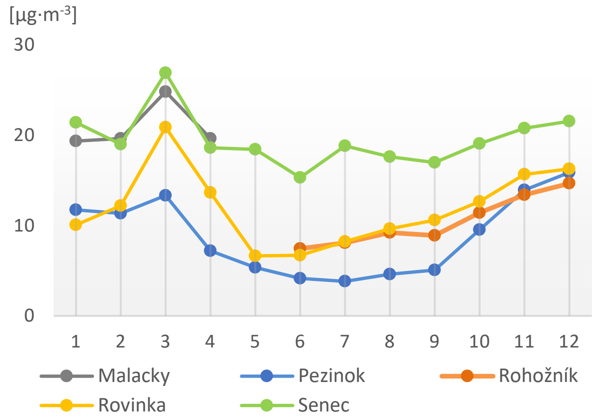
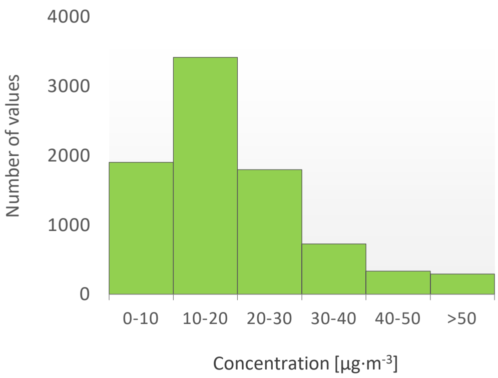


Fig. 3.16 *Histogram of values at AMS Senec.*



3.2.3 Ozone

Ozone monitoring is carried out at monitoring stations in Senec and Pezinok, measured concentrations did not reach high values (**Fig. 3.17**).

The highest concentrations of ground-level ozone generally occur in the warm months with high level of sunshine. **Fig. 3.18** and **Fig. 3.19** show the so-called daily course of O_3 concentration. It shows that concentrations increase with sunrise, peak around midday and gradually decrease in the evening to a minimum that occurs early in the morning. Large differences in ground-level ozone concentrations are also observed in the warm and cold seasons.

Fig. 3.17 *Monthly average O_3 concentrations.*

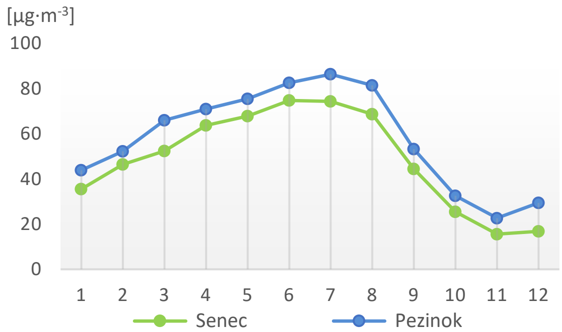


Fig. 3.18 *Daily O_3 concentration in January 2022.*

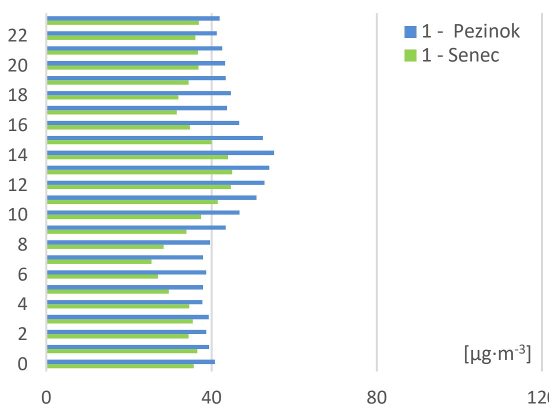
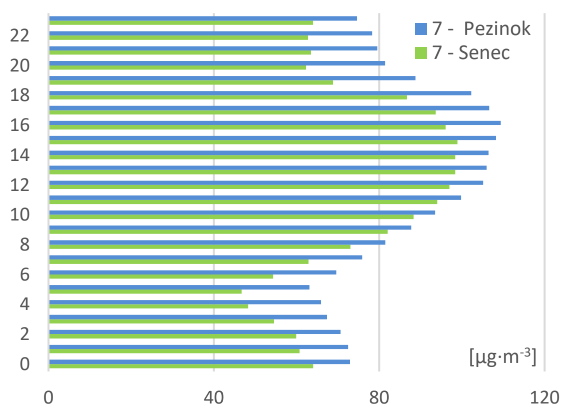


Fig. 3.19 *Daily O_3 concentration v July 2022.*



3.2.4 Benzo(a)pyrene

Benzo(a)pyrene is monitored in the zone Bratislava region in Rovinka (**Fig. 3.9**). The average annual concentration in 2022 was 0.5 ng·m^{-3}, thus not exceeding the target value (1 ng·m^{-3}). The highest concentrations of this pollutant were recorded in December at 3.3 ng·m^{-3}, reflecting worsened dispersion conditions and probably increased use of solid fuels in houses using fireplace inserts and stoves as an additional source of heating.

Tab. 3.4 *Assessment of air pollution by benzo(a)pyrene.*

		2018	2019	2020	2021	2022
Target value	[ng·m^{-3}]	1.0	1.0	1.0	1.0	1.0
Upper assessment threshold	[ng·m^{-3}]	0.6	0.6	0.6	0.6	
Lower assessment threshold	[ng·m^{-3}]	0.4	0.4	0.4	0.4	
Rovinka				0.4	0.6	0.5

4 AIR QUALITY MODELLING

Fig. 4.1 a **Fig. 4.2** show results of PM_{10} modelling calculated using the RIO model in combination with IDW-R (a more detailed description of the method is in Chapter 4 of *Air Pollution in the Slovak Republic 2022 Report*). The results of modelling with a higher resolution are processed for 2019 in a separate study [5].

Fig. 4.1 *Average annual PM_{10} concentration in 2022.*

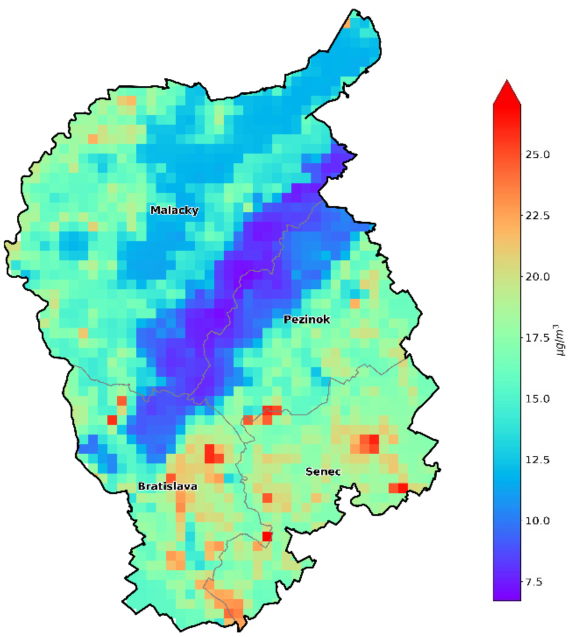
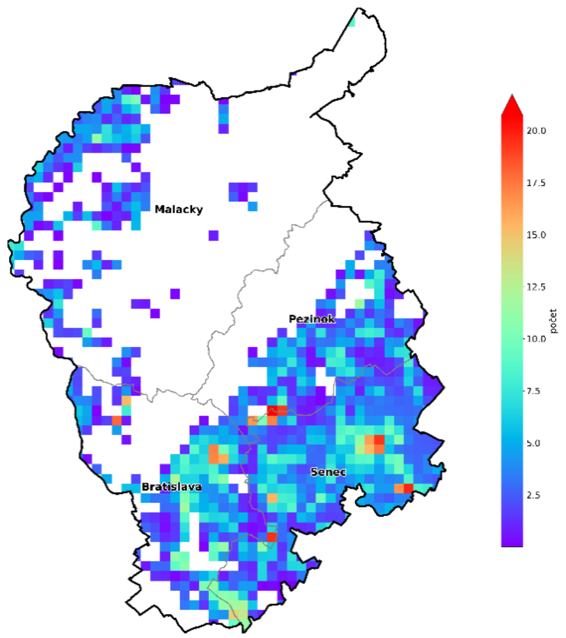


Fig. 4.2 *Number of exceedances of the PM_{10} daily limit value in 2022 (RIO, IDW-R). Only non-zero number of exceedances are shown.*



[5] *Krajčovičová et al.: Štúdia kvality ovzdušia v aglomerácii Bratislava. SHMÚ.2020. Available on https://www.shmu.sk/File/oko/studie_analyzy/Studia_BA_2020.pdf*

Map on **Fig. 4.3** shows the spatial distribution of average annual $PM_{2.5}$ concentrations according to the output of the RIO model in combination with the IDW-R model. According to the outputs of the model, the average annual concentration of $PM_{2.5}$ in the entire territory of the zone was higher than the limit value recommended by the WHO (WHO limit values are stricter than the EU limit). The highest concentrations are probably located in the area of the Danube Plain and in Záhorie region. In Bratislava, the highest concentrations are around busy roads in road canyons, as shown by high-resolution modelling in the study cited above.

The map of the spatial distribution of annual mean concentrations of benzo(a)pyrene according to the output of the RIO, IWD-R model (**Fig. 4.4**) shows the possible occurrence of higher concentrations in the area of Malacky, Gajary, Zohor, Hrubá Borša and Slovenský Grob. However, for more accurate information, high-resolution modelling with monitoring for these areas would be necessary.

Fig. 4.3 *Annual average $PM_{2,5}$ in 2022 output of the model RIO, IDW-R.*

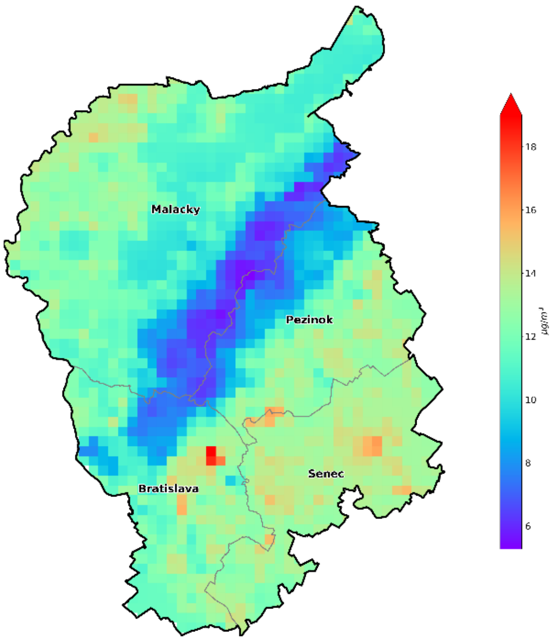
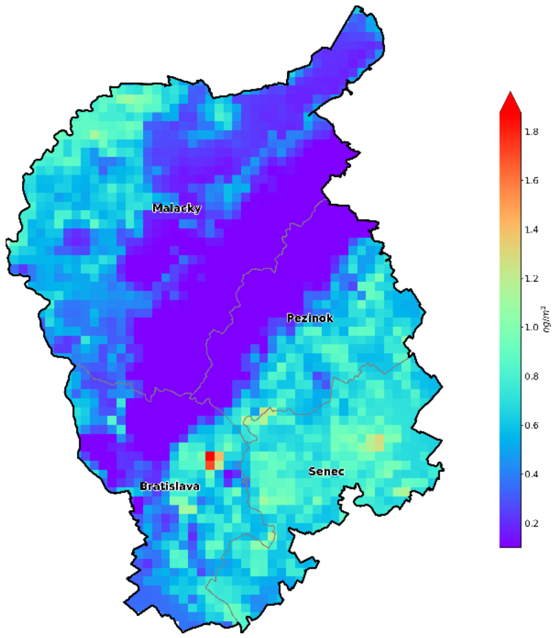


Fig. 4.4 *Annual average benzo(a)pyrene in 2022 output of the model RIO, IDW-R.*



4.1 Risk municipalities

Fig. 4.5 shows municipalities at risk of poor air quality, identified by the integrated municipal assessment method[6]. Risk level 3 corresponds to the highest probability of being at risk from air pollution. The methodology includes the rate of household heating with solid fuels, the impact of impaired dispersion conditions in the short and long term, the results of the CMAQ chemical-transport model, the RIO inter-field model and the results of high-resolution CALPUFF modelling on selected domains with a pre-sumption of impaired air quality.

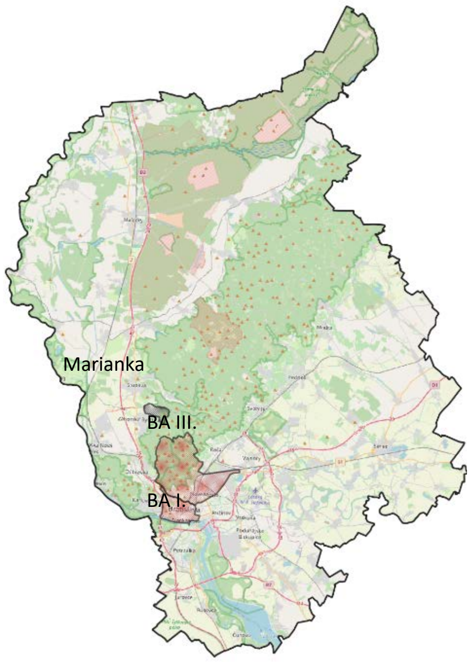
Municipalities where the limit value for PM, NO_2 or the target value for BaP was exceeded according to modelling with high spatial resolution were automatically assigned risk level 3, similarly to municipalities where the limit or target value was exceeded by measurement. A list of municipalities and their risk levels is available on the SHMÚ website.[6]

[6] *https://www.shmu.sk/sk/?page=2768*

Zones and agglomerations containing at least one municipality with risk level 3 shall draw up an Air Quality Improvement Programme. In this sense, municipalities with risk level 3 shall respond to air quality management areas. However, measures to reduce emissions must be implemented in the zone so designated in all municipalities with a risk level 2 or 3, ideally also in municipalities with a risk level 1.

The integrated assessment method assessment aims to identify areas where action to improve air quality needs to be targeted. Given the distribution of air pollution sources and the microclimatic characteristics of the area, it is likely that the level of pollution in the risk area will vary from one location to another. An idea of the spatial distribution of air pollution is provided by the results of high-resolution modelling, which are progressively added to the website[7].

Fig. 4.5 *Risk municipalities in zone Bratislava region and agglomeration Bratislava.*



5 SUMMARY

According to the monitoring results, the limit values for PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO and benzene were not exceeded in 2022 in the Bratislava agglomeration or in the zone Bratislava region.

Similarly, the target value for the annual mean concentration of benzo(a)pyrene was not exceeded at any NMSKO station. In the agglomeration Bratislava and the zone Bratislava region, no pollutant exceeded the limit value or the target value in the last three years. The target value for O_3 was exceeded at the suburban background monitoring station Bratislava, Jeséniova.

Based on the outputs of the study *Krajčovičová et al.: Štúdia kvality ovzdušia v aglomerácii Bratislava* (SHMÚ 2020)[8] we can conclude that in the Bratislava agglomeration, PM and NO_2 concentrations higher than the measured values at the traffic station Trnavské mýto may occur in the vicinity of busy canyon-type roads.

The impact of the petrochemical complex, located in Bratislava, Vlčie hrdlo, is only episodically manifested in the Bratislava agglomeration and in the neighbouring part of the zone Bratislava region, as shown by mathematical modelling with high spatial resolution. In general, on the basis of the available data, the zone Bratislava region can be classified as less problematic in terms of air quality.

[7] *https://www.shmu.sk/sk/?page=2699*
[8] *https://www.shmu.sk/File/oko/studie_analyzy/Studia_BA_2020.pdf*